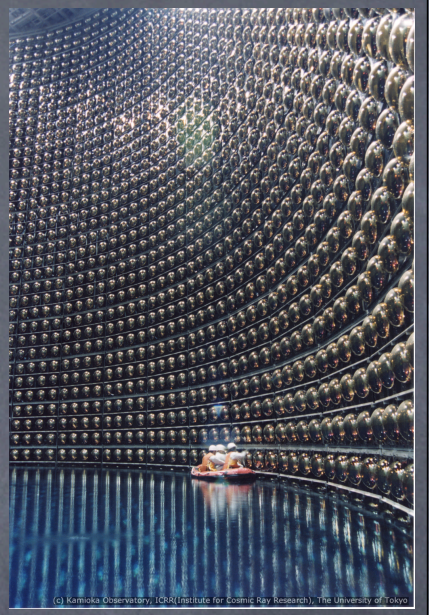
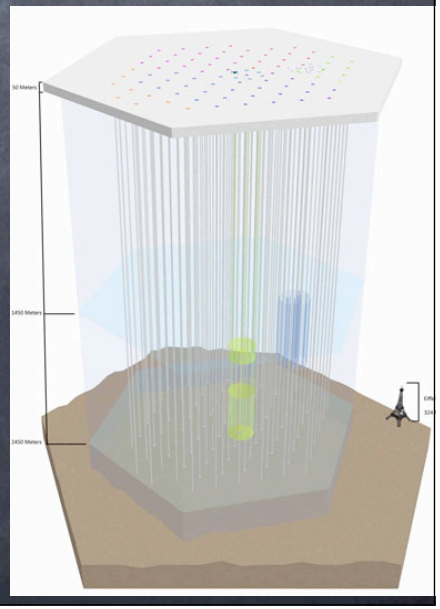
Physics with Neutrinos from the Cosmos

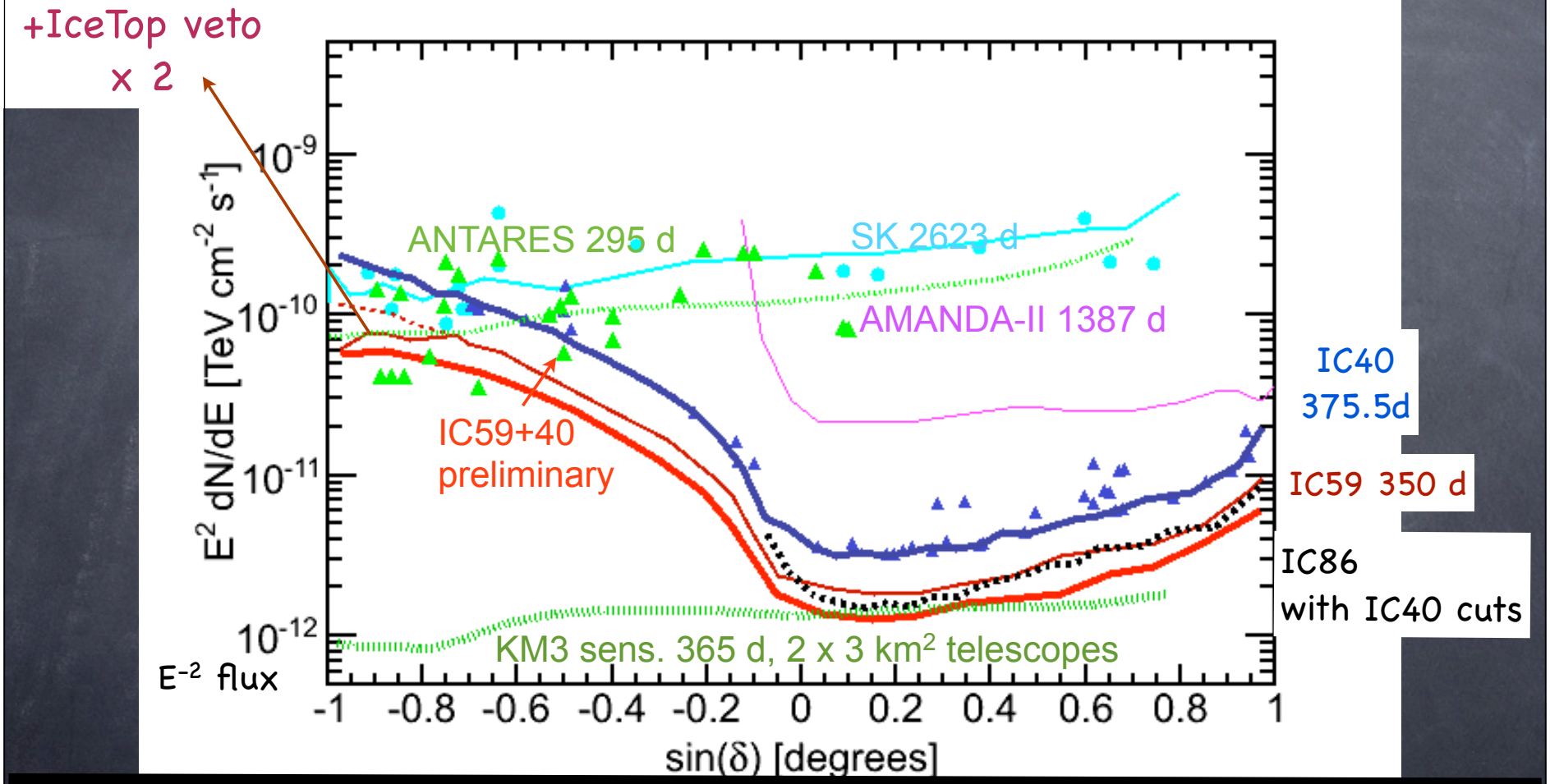
Astrophysical (solar) neutrinos and atmospheric gave a huge boost for high precision measurement of FUNDAMENTAL PROPERTIES of NEUTRINOS (mixing matrix). The US has played a relevant role and still does. What can we keep learning from neutrinos not produced in the Lab?



- Acceleration of Matter at UHE (needs > km^2 detectors due to low luminosity cosmic beams)
- New Physics: x-sections, VLI, DM
- More on Fundamental properties: high statistics measurements of θ_{23} and $\Delta m^2 23$ θ_{13}, hierarchy
- Experiments?



IceCube and worldwide sensitivities to cosmic beams: a US-driven success



IC40 unblinded. In < 1 month IC40+IC59 (x3 IC40) = better than preliminary estimates of full IceCube

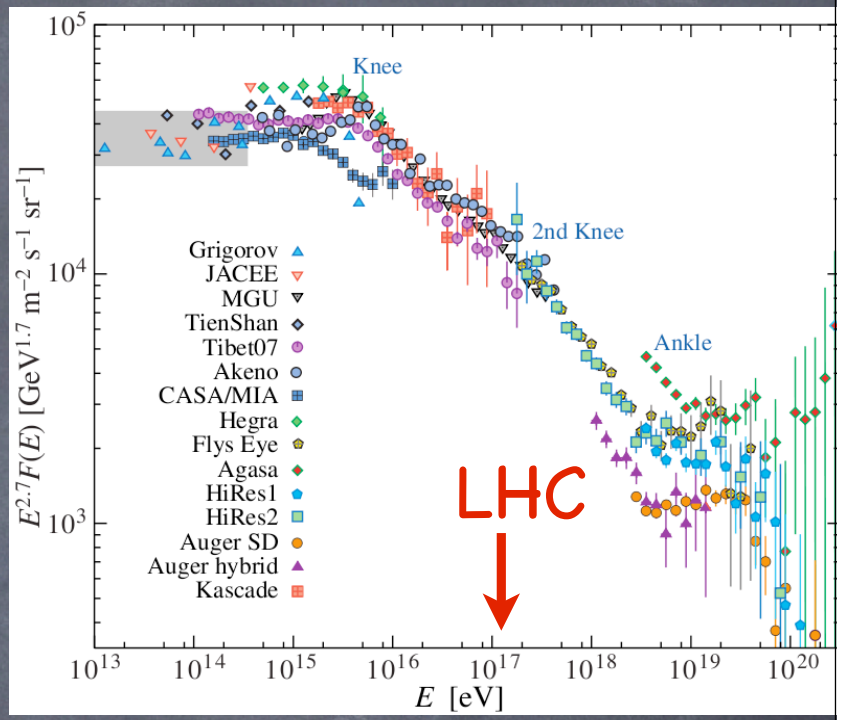
IC40+IC59+IC79+IC86 = about factor of 5 from the blue curve (IC40)

Acceleration of Matter

Fact: Protons (and nuclei) up to 10^{21} eV.

NO IDEA on what are the processes that are able to accelerate matter to such energies.

Future capabilities of accelerating particles in the Lab to Planck scale energies WILL profit of our understanding of such astrophysical processes.



PARTICLE Physics ⇔ ASTROPARTICLE synergy

Multimessengers:

UHE neutrinos and **Super-EAS Composition** measurements are strongly related.

Gamma telescopes without Neutrino Telescops would be a SHORT-SIGHTED program. **Neutrinos** are the **smoking gun** for understanding matter acceleration in the Universe and reinforce evidences from gammas.

UHE neutrino physics and connections to Large-EAS physics

- **New Physics** (x-sections beyond the SM and Violation of Lorenz Invariance using GRBs)
- Solve the **enigma on the drop-off of the UHECR spectrum**: is it E_{max} of sources of GZK cut-off?
  UHECR in Auger or other UHE-EAS are correlated to **neutrinos in IceCube** or other UHE neutrino detectors:
  - p or Fe produce the same spectral shape but Fe would not point back to sources due to the deflection in B-fields:
    If UHECR are heavy ⇔ no neutrinos, no anisotropies in UHECR

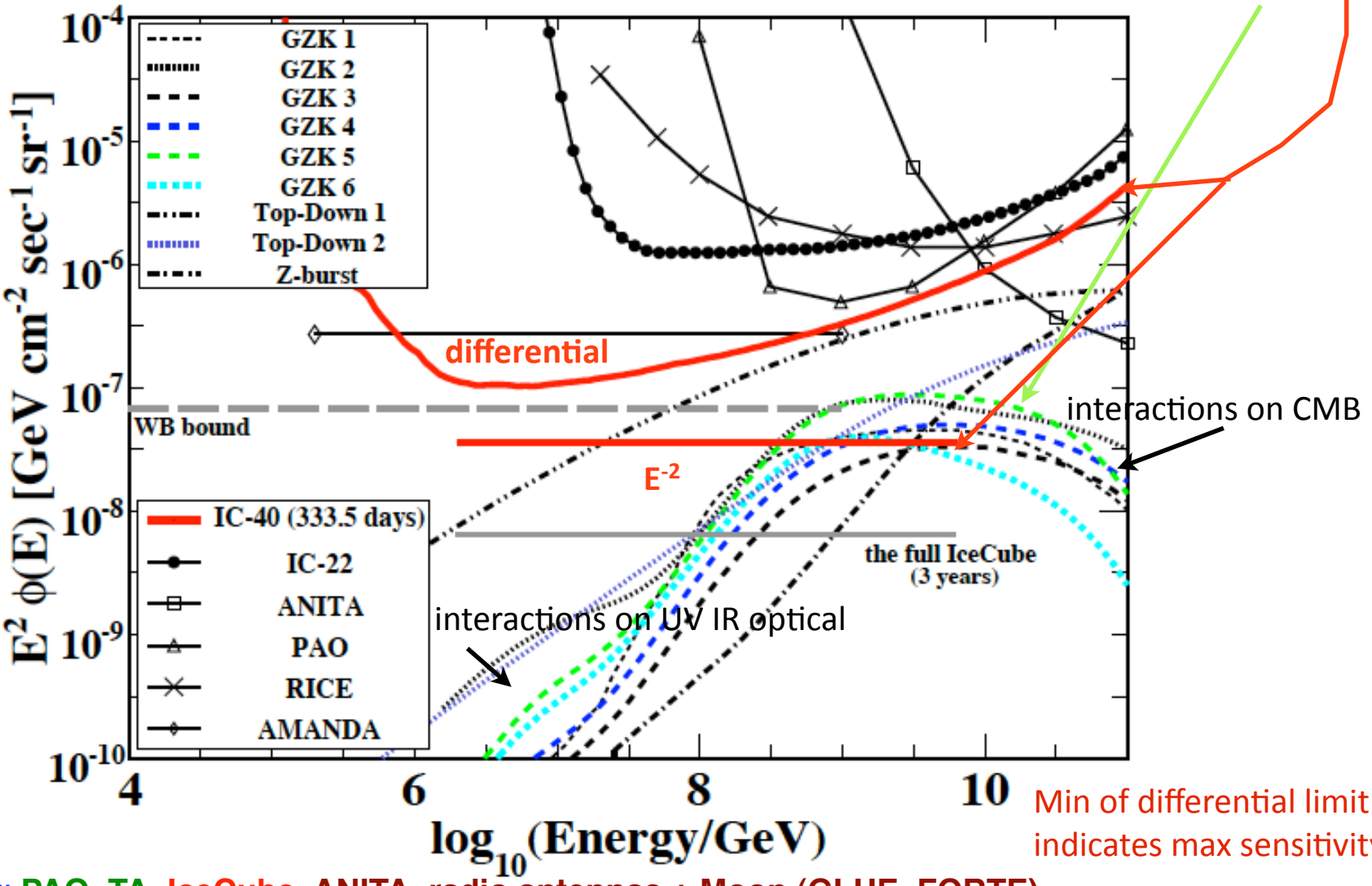
    CRs and neutrinos
  - **If UHECR sources are GRBs** ⇔ no neutrinos in the direction of

    UHECR protons because protons take much longer to reach us than neutrinos

Current status on Cosmogenic Neutrinos

W&B with cosmological evolution: 24.5 events in IC86/3 yrs (4.5 in IC40)

GZK 5 (M. Ahlers, et al., 2010): 4.8 events in IC86/3 yrs (using constrain from Fermi diffuse gammas)



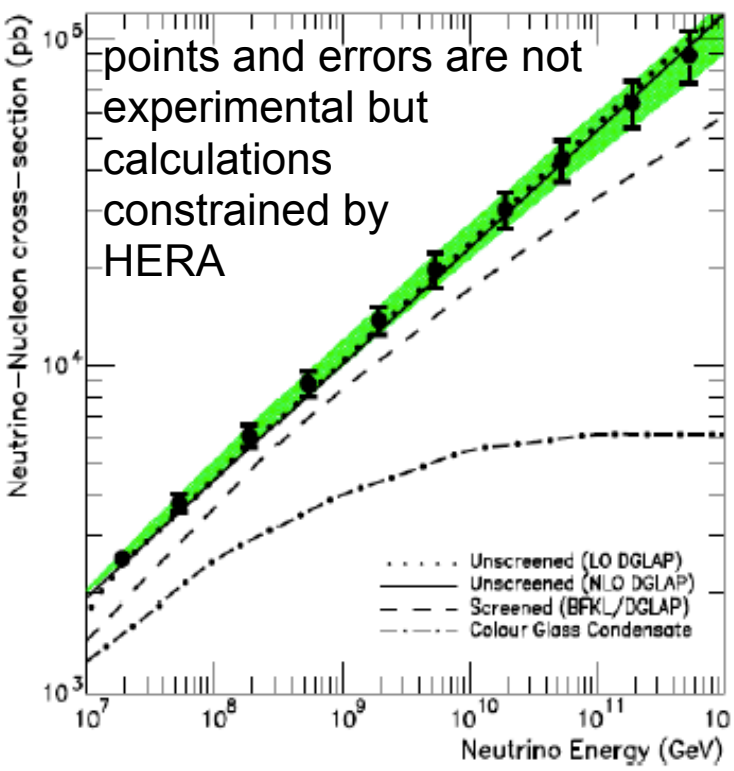
Min of differential limit indicates max sensitivity

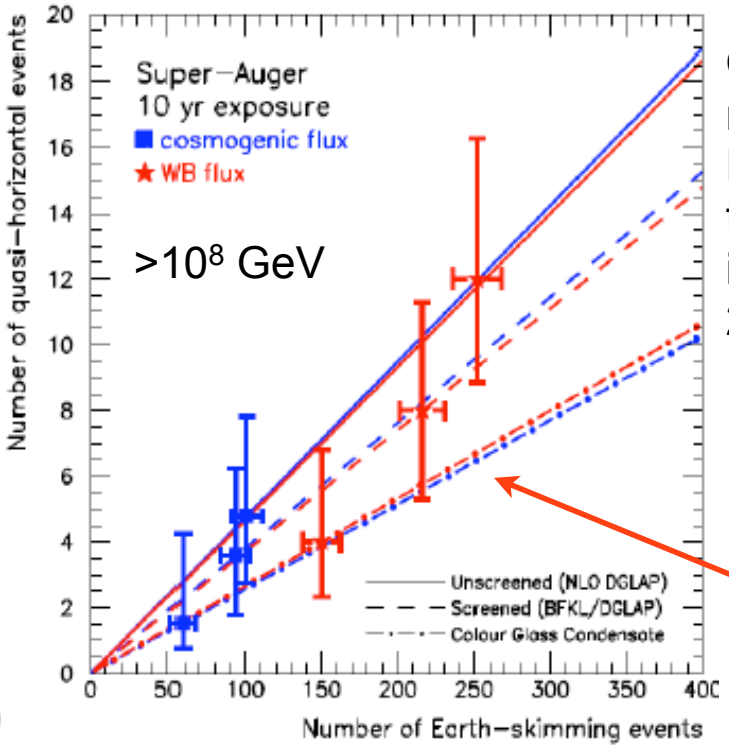
Present: **PAO, TA, IceCube, ANITA, radio antennas + Moon (GLUE, FORTE)**

Future: Auger North?, ARA?, JEM-EUSO, GLINT

Measure the X-section independently on the knowledge of the flux in Auger

Beyond HERA: probing low-x QCD with cosmic UHE neutrinos





Quasi-Horizontal neutrinos vs Earth Skimming tau neutrinos in a detector 22,500 km^2

WB **upper limi**t is higher than IceCube limits

The steep rise of the gluon density at low-x must saturate (unitarity!)
➔ suppression of the ν-N #-secn

The ratio of quasi-horizontal (all flavour) and Earth-skimming (ν_τ) events is sensitive to the #-section

Anchordoqui et al, hep-ph/0605086

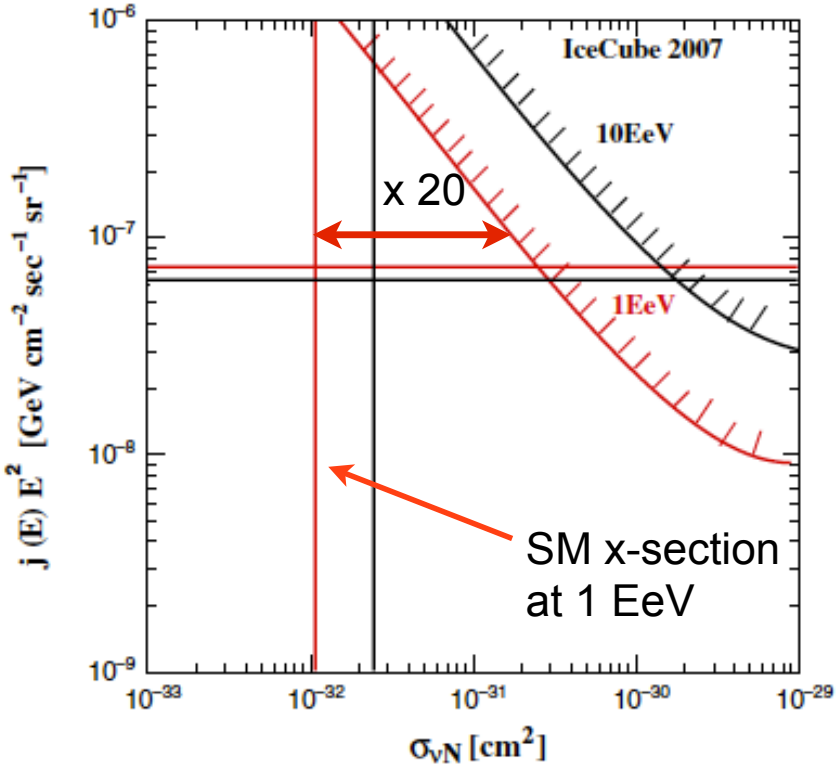
Other models foresee New Physics

Capability of UHE neutrinos to set limits

- `model independent' limit on factor that enhances the SM x-section at 1EV ($\sqrt{s} \gg$ TeV) to account for New Physics
- at 1 EeV a factor of 20 in x-section corresponds to the peak flux of UHE neutrinos 10^{-7} GeVcm^{-2}s^{-1} sr^{-1} (5 events/3 yr of IceCube).
- Unblinded data (IC40) make a factor of 40 at 1 EeV highly IMPROBABLE.

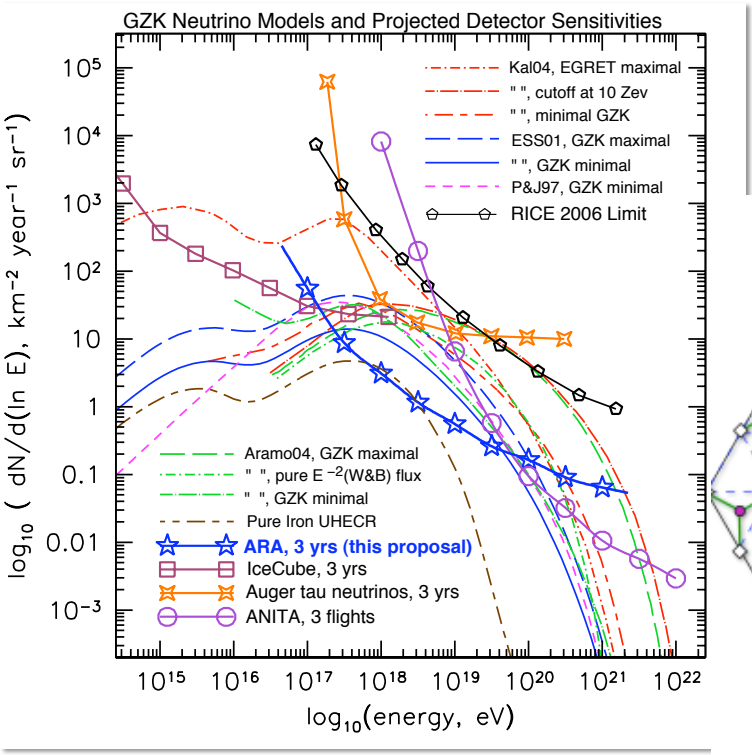
S. Yoshida, PRD 2010

Eg: models with higher x-section. BH production as a consequence of TeV scale gravity that may occur if space-time has > n=4 dimensions

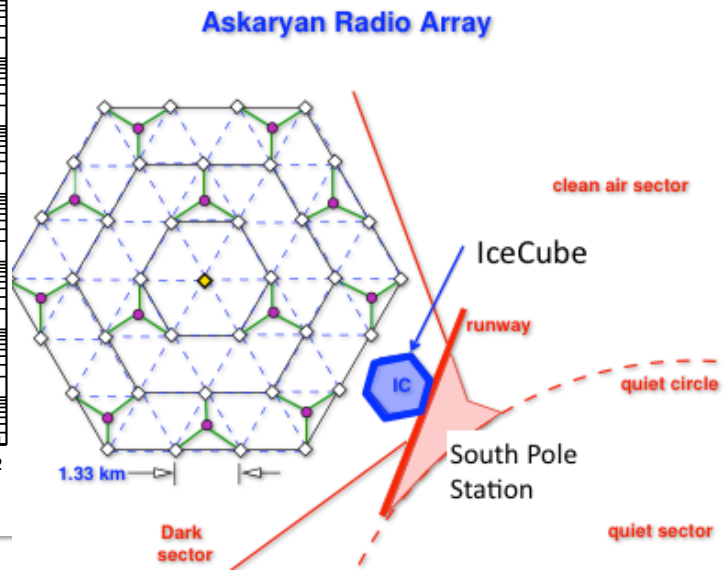


We need Large UHE detectors! EAS, neutrinos

Neutrino detection using Askaryan effect (radio Cherenkov emission)

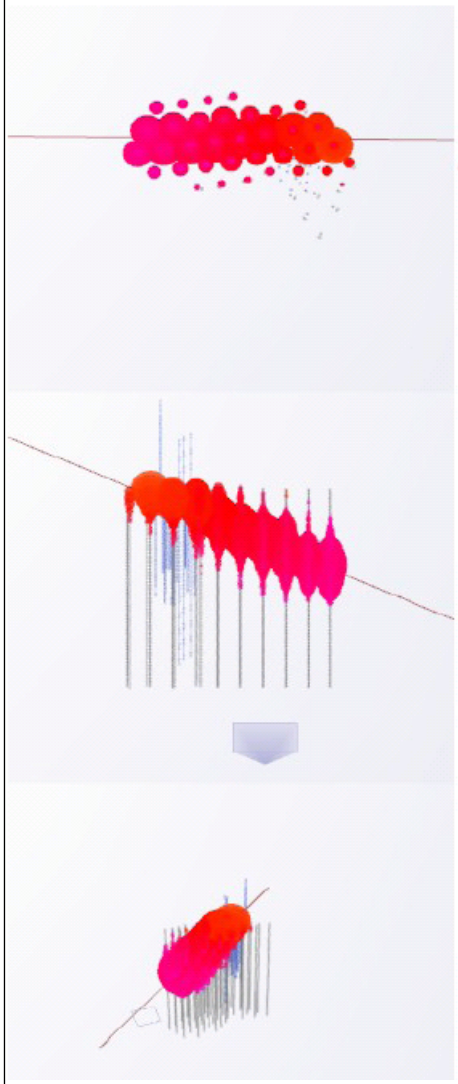


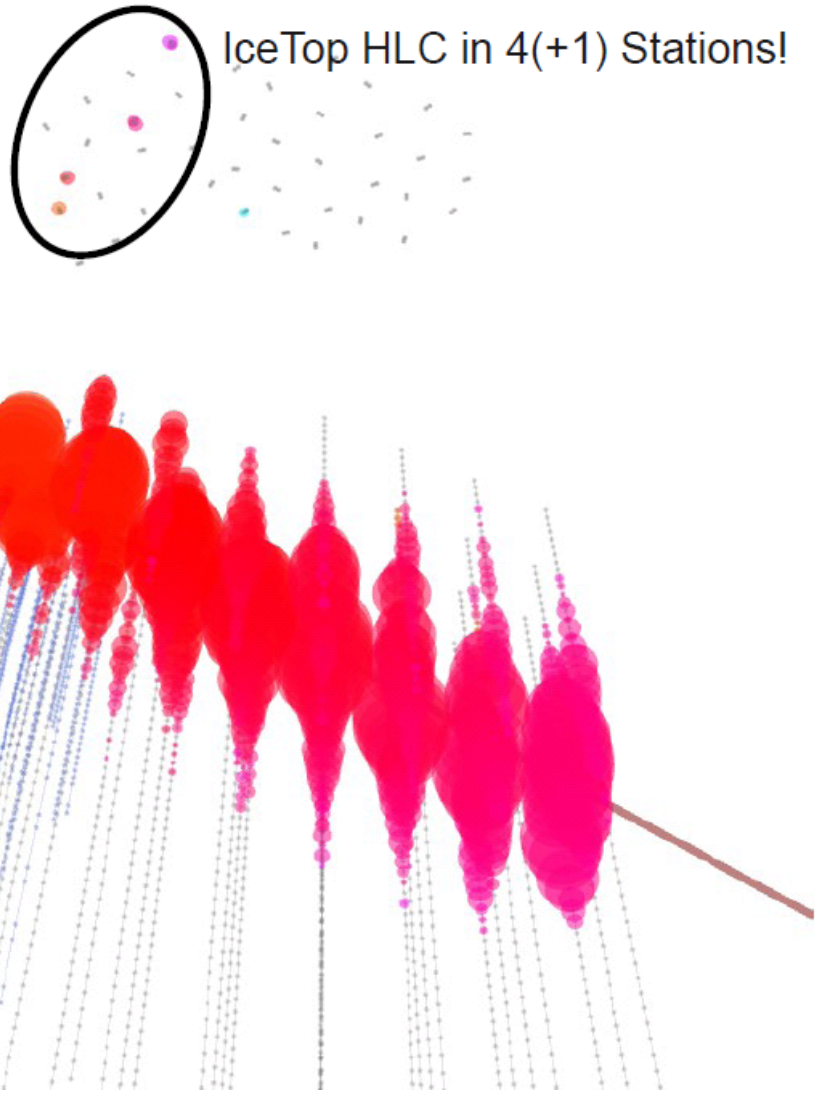
ARA has $10^{17.5}$ eV threshold!
ANITA balloon-born experim.



Gaisser EAS (T. Gaisser) :
Radio at Auger and IceCube (radio synchrotron+ Cherenkov)
MW (MIDAS, AMBER): bremsstrahlung emission in the MW

Biggest Shower in IC40 EHE Analysis





250,086 photons
65° zenith
10 PeV in detector

South Pole offers a unique opportunity for VETOED Neutrino detection

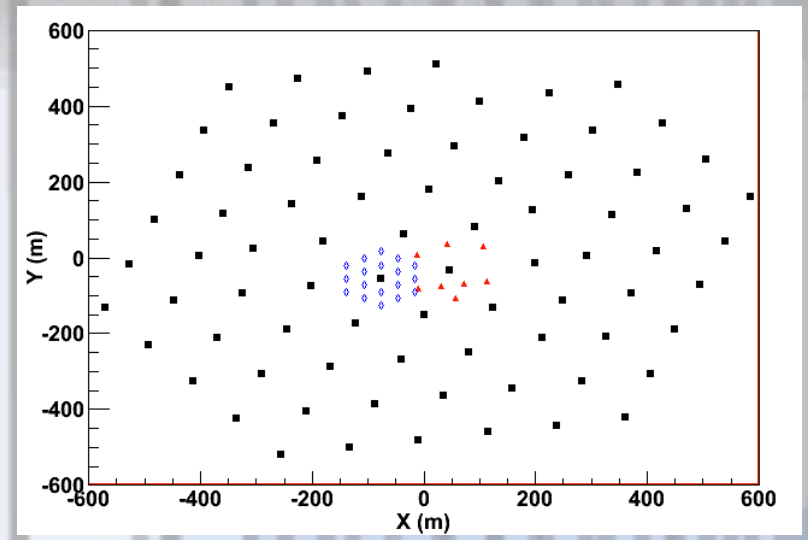
Powering the low energy neutrino detection

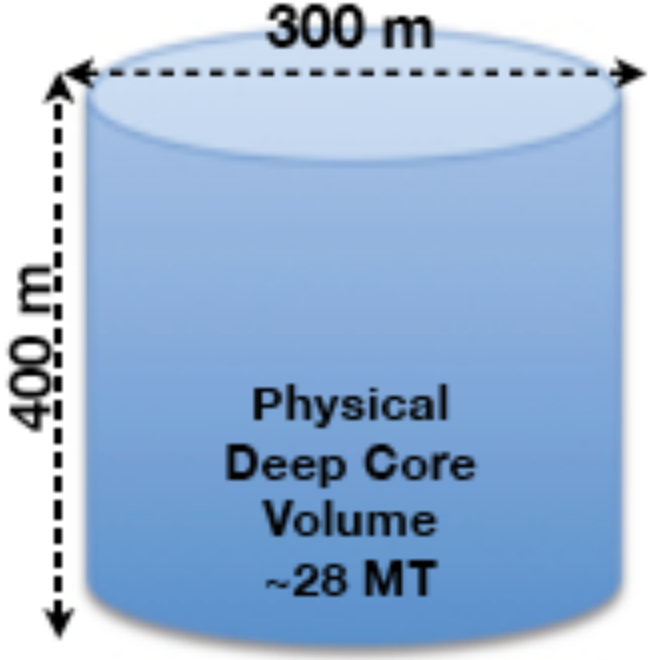
Large cores with larger photocathode area with VETO to discriminate atmospheric muons
With the veto of a large EAS and larger IceCube x 100 IceCube is possible. Beams from the cosmos have power law spectra!

LBNE (DUSEL Water Cherenkov) 3 x100 kton
Super K 50 kton

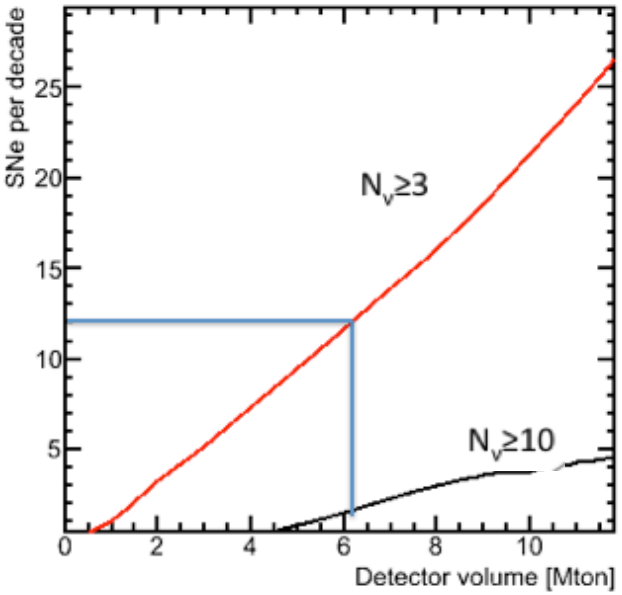
Size to scale, depth not to s

Extensions of IceCube under discussion





SN neutrinos and fundamental properties



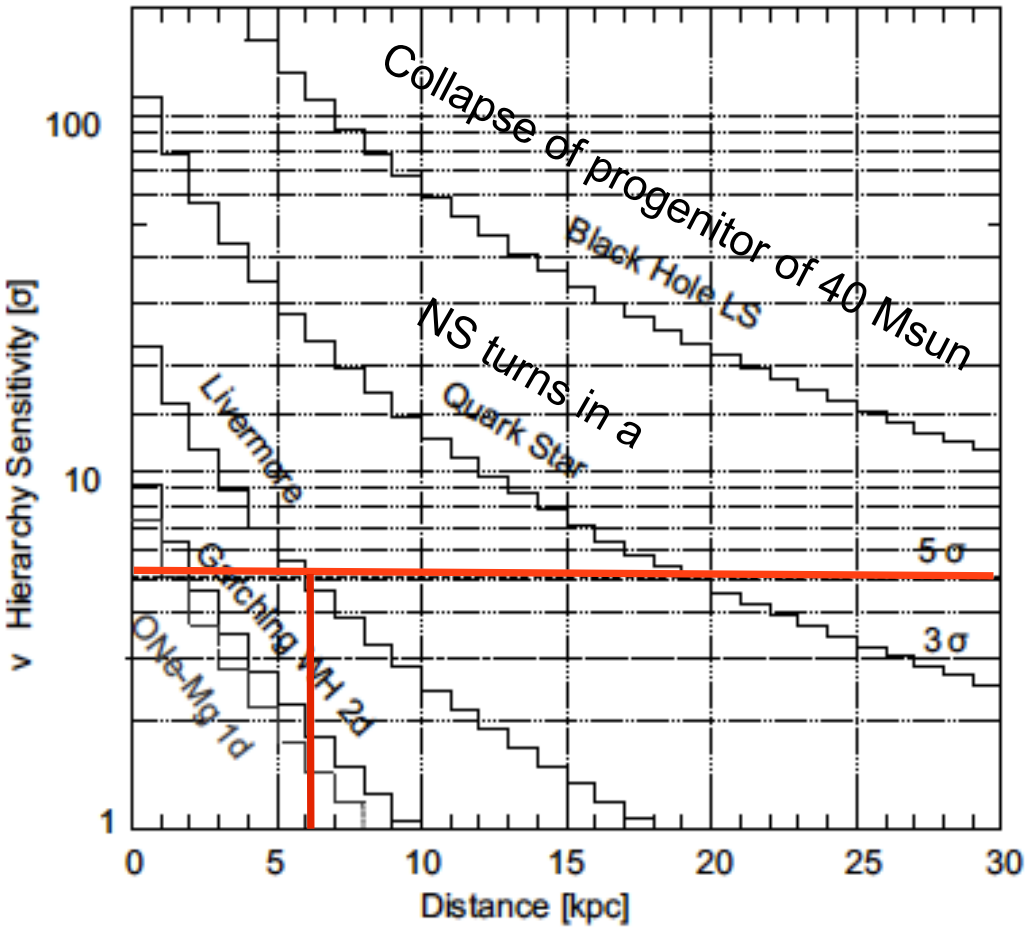
94% of signal is

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Deleptonization peak (10 ms) with electron neutrino scattering (independent on astrophysics)

$$\nu_e + e^- \rightarrow \nu_e + e^-$$

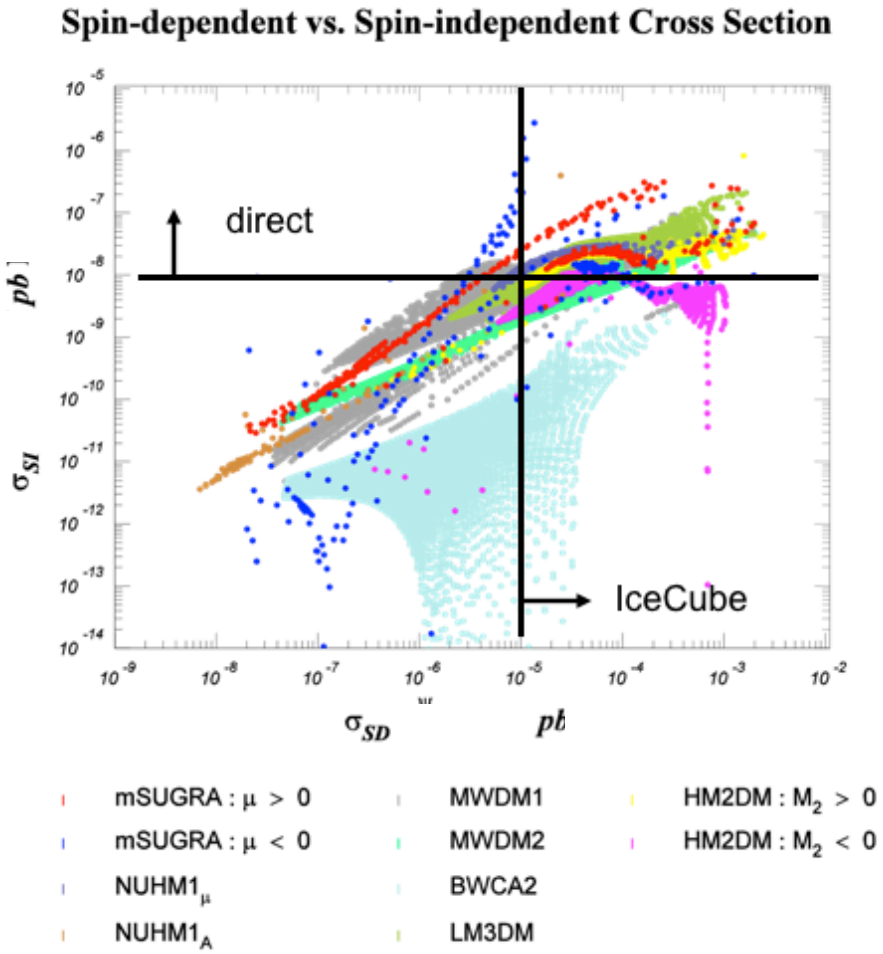
Standard deviations to discriminate Scenario A (NH) from Scenario B (IH with SN static density profile) for >50% of cases for $\theta_{13} > 0.9^o$
For d <= 6 kpc it is possible to establish NH w.r.t IH at 5sigma for Livermore model (after SN1987A)



DM

Spin independent (scalar) coupling: scattering amplitudes from different nucleons add coherently
=> large cross sections for large nuclei (direct detection) $\sigma_{SI} \propto A^2$

Spin dependent (axial-vector) coupling: incoherent interaction to the spin content of the nucleus
=> smaller by about A^2 than SI



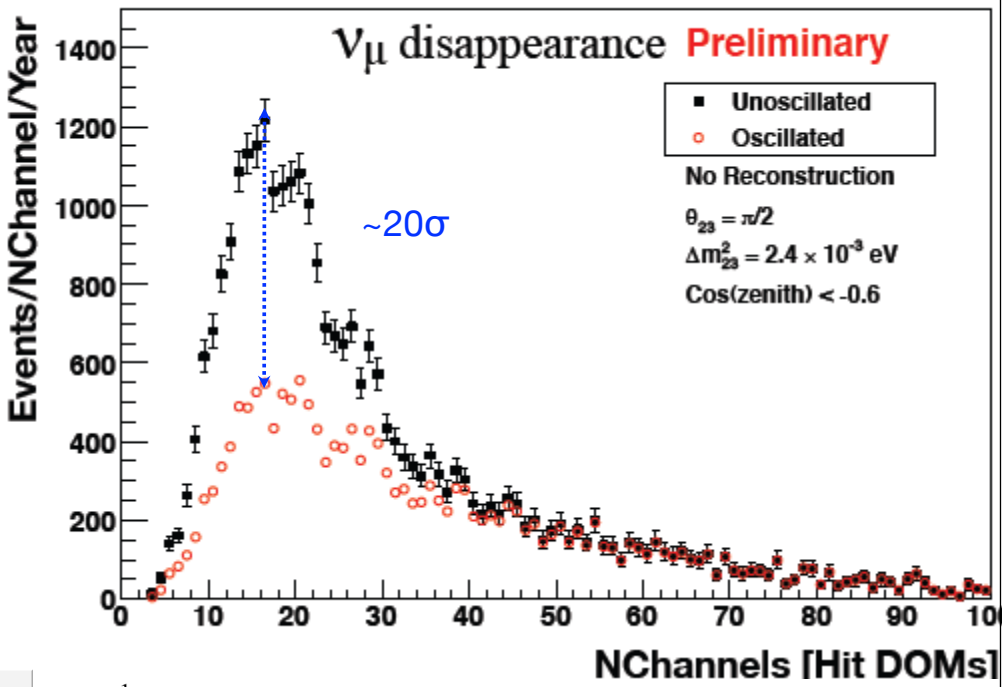
Neutrinos from the Sun (rich of H) are more sensitive to SD while direct detection to SI cross section. SUGRA models have both!

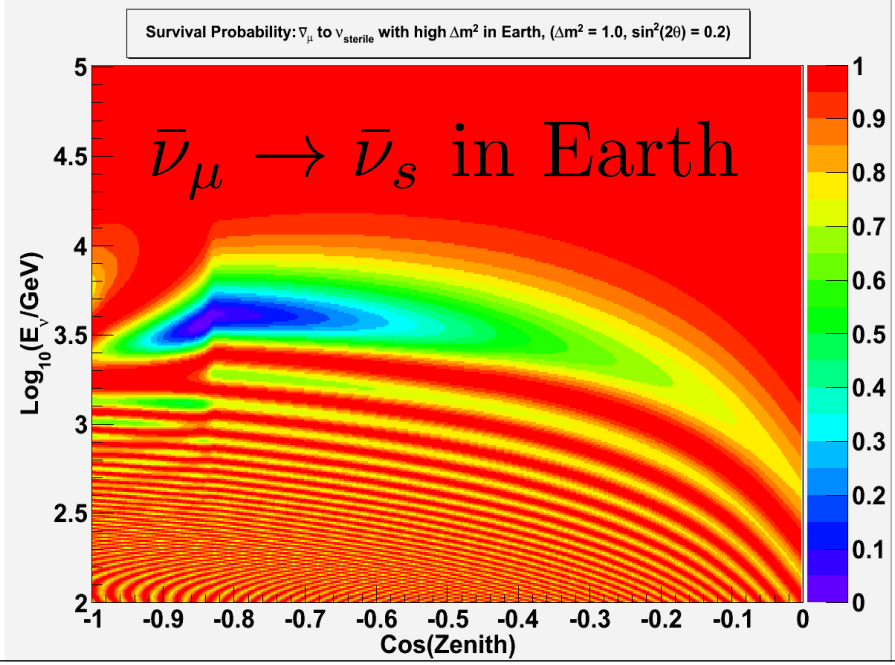
Tau appearance and hierarchy

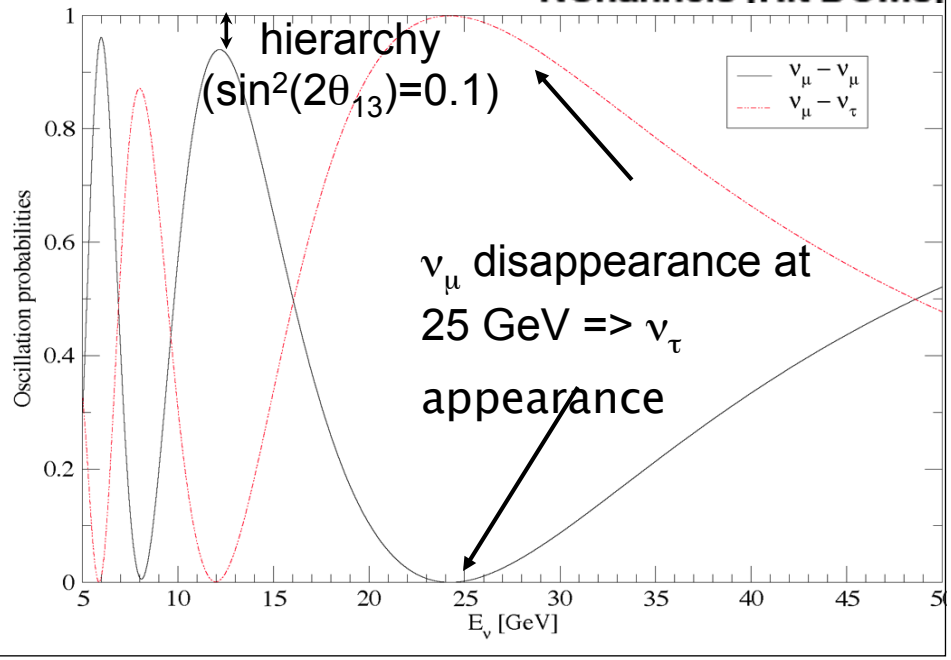
Mena et al, http://arxiv.org/abs/0803.3044v1

Resonance in effective θ_{13} angle traversing the Earth diameter at about 10 GeV

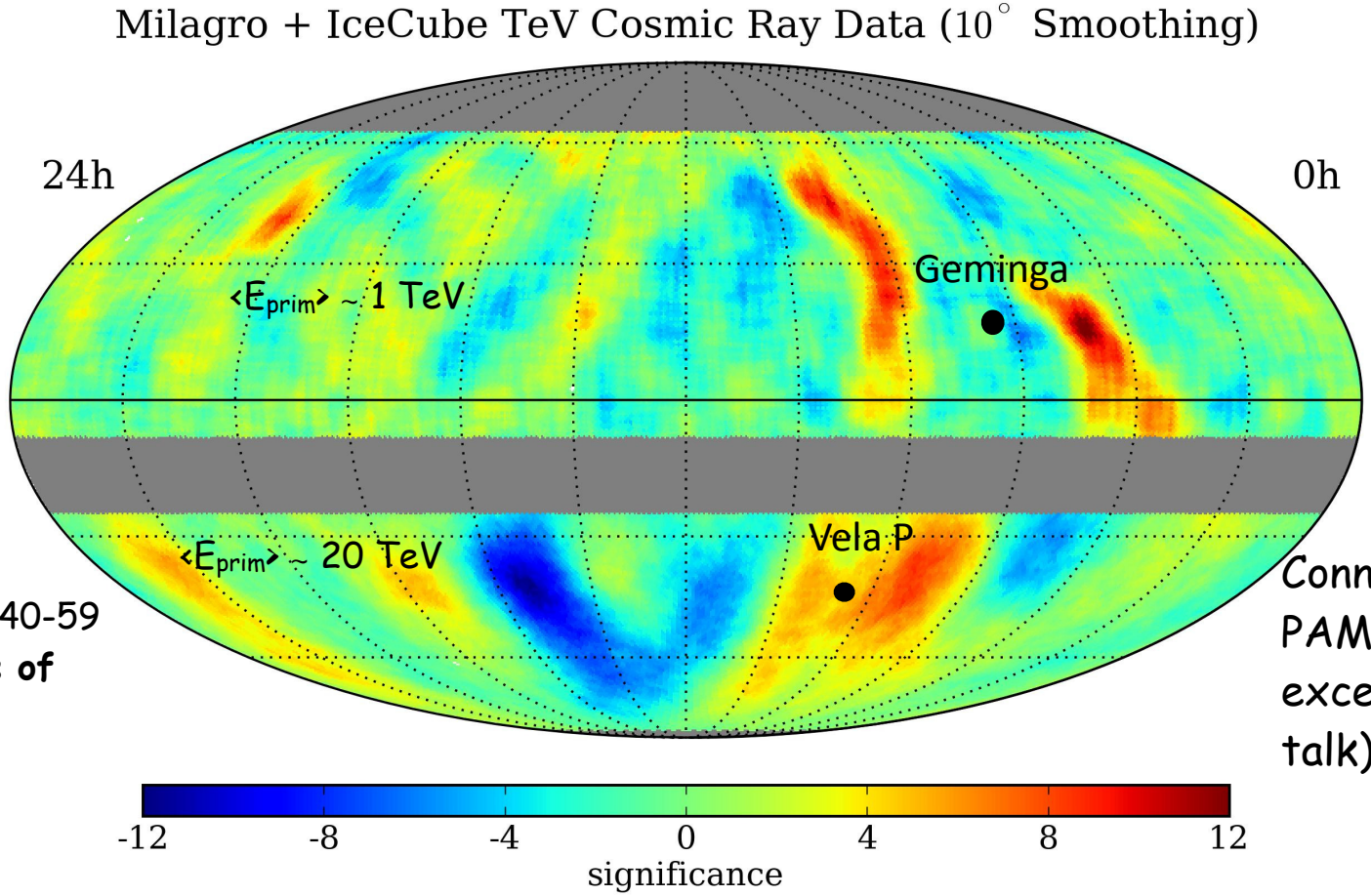
Sterile neutrinos (hints from LSND, MINOS, MiniBooNE of different nu and anti-nu oscillations, reactor neutrino anomaly, cosmology can be explained by sterile neutrinos)







Observation of small scale anisotropies



IceCube 22-40-59
55.8 billions of muons!

Connected to PAMELA excess (Feng's talk)

Pulsars/SNRs suggested to explain PAMELA excess in alternative to DM.
What about if sources of CRs are more extended? (superbubbles, Butt in Nature 2009)
A vetoed and larger IceCube would make a x 100 for soft spectra from the Galaxy.

R&D on detector NEEDED!!

A GLASS TUBE FACTORY

~100 x

PMT cost
50% dynode column
50% Glass bulb

AN IDEAL PMT DYNODE FACTORY?

Experimental Need: New Photodetectors

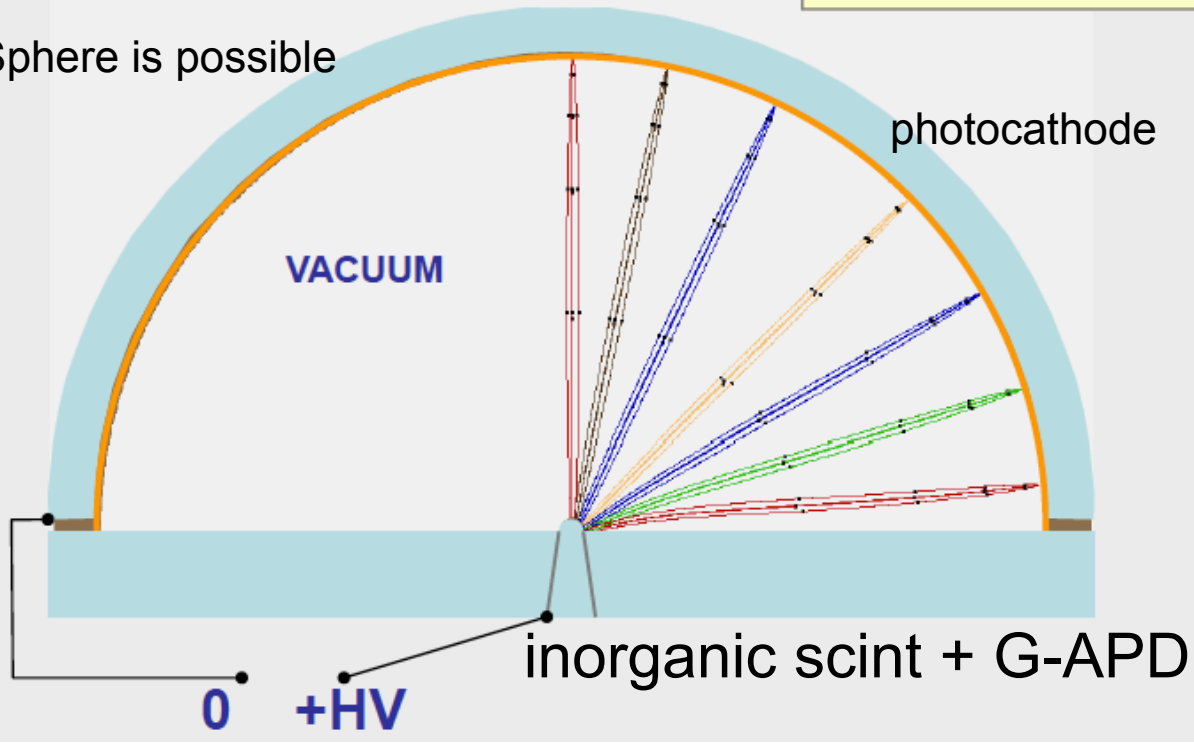
D. Ferenc

ABALONE

Cr-In-Au Vacuum Seals
=
Voltage Feedthroughs

- → 5-inch diameter
- → 20 kV
- → 45 deg. angular spread
- → 0.25 eV initial electron energy

Sphere is possible



17" sphere containing 31 PMT's of 3"

(KM3NeT)

Simple: no dynodes, no feedthroughs, radiopure (no metal parts), glass or quartz + photocathode film in the vacuum + readout outside, can be made spherically sensitive